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The Forum Series.—No. 7

CRAFTSMANSHIP AND SCIENCE

(Presidential Address to the British Association, September 5, 1928.)

BY

PROF. SIR WILLIAM BRAGG

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WITH TWO SUPPLEMENTARY ADDRESSES

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I

Craftsmanship and Science[1]

WHEN, nearly a century ago, the founders of our Association drew up a statement of purposes and rules they gave prominence to the words "to obtain more general attention for the objects of Science." Since that time we have tried continuously to fulfil our self-imposed task, not, I hope, unwisely nor untactfully, nor without success. For this purpose we have on many occasions and in many ways endeavoured to describe the progress of our researches, and to present the consequences of discoveries as they appeared to the discoverers. With your permission, I would like this evening to add something to the story. I would claim as my justification for doing so the fact that in the last few years scientific enquiry has advanced at a rate which to all is amazing, and to some is even alarming. On the one hand, the application of science to industry has become increasingly important and obvious, as was so clearly shown by our honoured President of two years ago. Especially at the present time, when our country is struggling to free itself from distress due partly to the war and partly to violent changes in economic conditions, is it of interest and importance to consider what science is doing and can do to accelerate recovery. On the other hand, in the less material realms the applications of recent research have aroused wide interest, as may be exemplified by the influence on philosophic thought of the new discoveries in physical science, or by the effect of last year's remarkable Address from this chair.

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[1] Presidential Address to the British Association on September 5, 1928.

I cannot deal in the time allotted to me with all the issues that are suggested by these considerations. I propose to limit myself in a manner which my choice of title will suggest, and in speaking of "craftsmanship and science" to pay attention more particularly to the relations between science and the craftsmanship of our own country. I shall not, however, be able to confine myself strictly within these limits because the entrance of science into our most material businesses cannot be considered without reference to the part that science plays in the whole range of our thoughts and actions.

The term "craftsmanship" requires definition. I am supposing it to mean the skill which is exercised in the production of whatever is wanted for human welfare. Imagine an island so cut off from the rest of the world that its inhabitants must depend on themselves for the satisfaction of all their desires, for their food, even if they have no more to do than pick fruit from a tree, for their clothing, for their housing, and other material things. They must also find their own means of satisfying less material cravings: for if they have intelligence they will look for means of studying themselves, their neighbours, and the world round about them. Their eyes and ears will ask to be used for the satisfaction of a sense of beauty in form and colour and sound, and their minds will try to reach out beyond what can be seen and heard. It is impossible to proceed to the satisfaction of these desires without the handling of materials, and craftsmanship begins with the skill exercised in the handling.

What the islanders succeed in achieving by their craftsmanship may justly be described as their wages, they being their own employers. If their wages are to be raised they must somehow increase one or more of the factors on which their success depends. They must be more diligent in the discovery of materials for which a use can be found; they must become better acquainted with the properties of those materials; they must develop their constructive skill. If they are too primitive to have developed the use of mechanical power they must do everything with their own hands, guided by their own intelligence and their own feeling for what is beautiful and fitting. At every step enter the qualities that go to make craftsmanship, as I would interpret the term. There is knowledge of materials, there is imagination, there is technical skill; perseverance is wanted, love of the work itself, sympathy with the use that is to be made of it, and with the user. Clearly, on the craftsmanship of the islanders will depend whether they have enough food to go round, enough clothes to wear, whether they have leisure for anything beyond the labour that satisfies their barest necessities.

And, of course, this isolated group of people will have some characteristic estimation of what kind of wages they want. Their energies may conceivably be devoted only to the production of things that satisfy bodily desires, or they may be bent also on nobler things. I need not consider that point as I am not trying to picture Utopia. All that this image is meant to convey is the idea of craftsmanship and its fundamental importance. Nor is the account yet complete; far from it. It is not only that the products of craftsmanship are a necessity if the islanders are to live at all: craftsmanship has a value in itself.

There is in men, more in some, less in others, the natural desire to use what faculties they possess. It is a fact that love of good work and delight in successful accomplishment are powerful motives, and when satisfied are sources of real happiness. Of all the motives that sway the world these are among the purest and best.

The power to produce in plenty what is wanted is, of course, only one of the great problems that a community has to consider. There is also the endlessly difficult question of distribution, of the manner in which each working individual is to receive his share of the wages. The two problems cannot be separated entirely: the means directed to the solution of one contribute to the solution of the other. But I must not attempt too much: science is in the first instance concerned with the production problem; the distribution problem follows.

Let us extend our image a little; let our island be discovered and put into communication with the outside world. An exchange of craft work sets in: the islanders discover new wants that must be satisfied, and they pay for the necessary imports by exporting what they make themselves. But the exports must be made to satisfy the tastes of the outside peoples, or there will be no trade. So the islanders now find that they must no longer consider their own tastes entirely: they must accommodate themselves to a more general conception which is only in part their own. It may happen that under the new conditions they become less and less self-contained. Some things which are necessary to life, such as food or clothing, may become imports, being no longer produced, at any rate in sufficient quantity, within the island itself. And now the people are very firmly tied to the rest of the world;

they must give that they may receive, and they must please in order that others may be willing to take. We may say that their craftsmanship is now judged more critically; and more than ever it becomes fundamental to well-being, even to existence. The conclusion I would draw from this very simple little analogy is that a people lives on what it makes or earns, and that its success depends on its craftsmanship. A people cannot expect to be provided for: it has no rights.

I would ask you presently to consider the difference between the craftsmanship of an early civilization and that of our own more complicated times. But before doing so let me say yet one or two words about the older forms.

We have a profound feeling for any example of an old craft, and for very good reasons. Among them I do not include the sentimental regret that, in some cases, a past-time skill seems to have disappeared. We may be sorry, but after all it is but a receipt that has been lost and may be found again any day, if proper search is made for it. Modern knowledge and methods of analysis are at least good for that much. Nor is the collector's pride of rarity the worthiest feeling that the old specimen inspires.

Our affection for it and the reverential care with which we handle it are due to the fact that it represents to us the labour of a people, labour into which knowledge, imagination, love of beauty, technical skill have all entered. The most of what was once used in every-day life has long disappeared; even such more durable things as houses and ships, roads and cultivations, may have ceased to be. The few objects that survive must be taken as examples of what has been lost. And on the showing of the student a spirit will emerge from an old vessel as great as that which issued when the fisherman of the Arabian Nights unsealed the pot that had long been lying at the bottom of the river. It is the spirit of the bygone people that takes shape before us.

The Greek gave exquisite form to his vase and decorated its surface with equal art. He copied from the growing things of Nature the adjustment of lines and surfaces which give the sense of fitness for a purpose. The outlines of his vases are so perfectly adjusted that their representation in a drawing will not bear alteration by the width of a line. That the Greek should with so much skill take lessons from what his perception made clear to him, and should with so much care choose his materials and mould them to his purpose, is what we should expect from a nation that shows also in its literature a passion for justice and harmony. The fine accuracy of his line is in agreement with his delicate sense of differences in thought and words.

The Roman developed the principle of the arch, and enough remains of what he built to show the daring and the power of his work. The great arches that spanned his public buildings seem to stand for the Roman rule and law under which the whole world might find shelter and be at peace.

The sword of the Indian workman was gradually brought to its temper by an infinite series of local applications of heat alternating with the few blows that could be skilfully given while for a moment it was in the workable state. The poverty of the craftsman's appliances, the meagreness of his little fire and the scantiness of the tools with which he made his way bit by bit to his final achievement, are in consonance with his life of small details ruled by overmastering ideas.

I need not illustrate further. It is indeed well known to you all that the craftsmanship of a people is an expression of the best of its very self. It is to the underlying reason that I would draw your attention now. The mind of a nation is so expressed because its craftsmanship, interpreted in its widest sense, represents its efforts to live. Under this strong compulsion the nation produces results which range from pots to poetry, and all its products are stamped alike. That which we do ourselves is as representative as a Greek vase or a Roman aqueduct or a suit of armour from Milan. The craftsmanship of a nation is its very life. Even if we consider it only in relation to the production of material things, the state of a nation's craftsmanship is an index of its health.

As a people departs from its primitive condition so also does its craftsmanship. I would ask you to consider the nature of the change. The elements of craftsmanship in its original form centre round the individual. In his brain are the knowledge and imagination, in his hands is the skill, and round about him lie the materials and the tools of his craft. But as the years go by it becomes impossible that all the knowledge and all the technical skill should be found in one person, and all the tools be owned by him. The craftsman becomes an association of men, a great manufacturing firm, even, we might say, a nation, if all the members of the nation contribute through Government intervention and control to the maintenance of some industry. Many hands, working in an alliance which is often unconscious, are employed in bringing a product to its finished form. It is a long step from the simple workshop of the old single-handed craftsman to the vast complex factory of modern industry.

If now we ask ourselves what has brought us to this new kind of modern craftsmanship, this dependence on machinery with its wealth of production, its clattering, bustling activity, and its compelling influence on the lives of all of us, we find that one simple cause has been continuously operative. It is nothing more nor less than the urgent wish of the individual to better his own condition; and, in his disinterested moods, the condition of his neighbours. The change could never have been prevented.

When Hargreaves thought that by a mechanical arrangement he could manipulate several spinning-wheels at one time, and succeeded, so that he had more wages to spend on his wife and children, he was obeying a universal and natural impulse. Hargreaves' neighbours, being left behind in the competition for wages, pulled his house about his ears. But in the end they, too, found themselves to be turning many spinning-wheels where formerly they had handled only one. Then they, too, had more money to spend. What other turn could things have taken under the circumstances? What happened in this isolated incident is repeated again and again in every craft, and in sequence change after change marks the road that stretches far from its beginnings.

Quite apart from all considerations as to whether the new is better or worse than the old, more beautiful or less beautiful, whether it calls out the best in man as well as the older ways, or whether it fails to do so—apart from all comparisons of this kind stands the fact that the change is due to natural impulses which will not be gainsaid. The results have to be accepted. We cannot put the clock back. We cannot, let us say, wipe away the great steelworks of the world and replace them by thousands of individuals each with his single anvil and single hammer. We cannot replace the great ships of Glasgow by a multitude of little sailing boats. The plain truth is that modern craftsmanship with all its noise and ugliness is giving food and clothing, warmth and interest, to millions who otherwise must die. It is ungrateful to find fault except with sympathy. Let us try in all possible ways to mend its offences and soften its hardships, but in all honesty let us recognize that we live on modern craftsmanship in its modern form. We are each and every one of us responsible for the present conditions as long as we insist on spending money to the best advantage.

At this point it is convenient to refer to a matter which would be of little importance if it did not seem sometimes to put modern craftsmanship in a wrong light. We are continually discovering instances of the marvellous skill of the craftsman of thousands of years ago. There is here, however, no disheartening implication, as has sometimes been asserted, that men can no longer do what was once in their power. To those who look into what goes on in a factory or a mine, in the field or on the sea, there are innumerable instances of beautiful craft work, beautiful because of their fitness for their purpose, their balance of design, their ingenuity, their history, their growth under human perseverance and thought. Every one of us can bring to mind instances of technical skill demanding imagination and intelligence as well as manipulative power which could be set alongside any instance in history. Let me name only one: could anything surpass the drawing of fibres of quartz, finer by far than a human hair, by means of the bow and arrow? It was a feat to imagine that it could be done, to anticipate that when done it would fill so perfectly

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from one great feature of the ship to another, and presently from detail to detail; and you find that the whole structure is linked by innumerable ties to the research work of the laboratories. Craftsmanship in its urgent need has called upon scientific knowledge for aid, and the mighty growth is due to the response. Indeed, it is not only craftsmanship that has grown, but also science itself.

If you hinder the growth of science in any way you hinder the growth of craftsmanship. Now it is an important fact that science advances over a wide front, and the various branches of it move on together: not absolutely keeping step with each other, but preserving a general line. It has been suggested that science might refrain from development in some directions or, even as our good friend the Bishop of Ripon said at Leeds last year, we might proclaim a ten years' holiday. But you cannot prevent interested men from making enquiry. You cannot prevent the growth of knowledge, you cannot even make a selection of those points of advance which will lead to certain select classes of results. No one knows what is over the hill. The vanguard moves on without any thought of what is before it. That is why, if the march of science is to be conducted in an effective and orderly way, were it only for the purposes of industry, there must always be a certain number of laboratories or parts of laboratories where scientific research has no immediate thought of possible applications.

If I read modern industrial conditions rightly the closeness of the connection between craftsmanship and science may be illustrated in yet another way. It is, I think, a fact, and a remarkable fact, that the most active of our modern industries are those which are founded on recent scientific research. The most notable is, of course, that of electrical engineering. The year that sees the celebration of our Association's centenary will witness also the ceremonies that commemorate the basic experiment of Faraday. It is difficult to sketch in a few words the great edifices that have been built up on the discovery of electromagnetic induction. We might look upon it financially and picture, as some of my hearers can do, the amount of capital involved in electrical undertakings throughout the world—electric lighting, electric transmission of power, cables, and now wireless, not to mention all the minor uses to which electricity is put. The transference of matter, of intelligence, of thought, of sound, even of vision, is largely dependent on electromagnetic action. If we are not familiar with financial quantities, let us just think for a moment of the change in our lives if every electric current ceased to run; and let us realize that the whole mechanism of modern intercourse would fail, and that populations born to use it would be brought to dire distress.

Though the electrical engineering industry with all its branches may be said to have its source in a single laboratory experiment, yet it has grown by the continuous adaptation of fresh streams of knowledge. The huge American corporations maintain research laboratories costing millions of pounds annually, and find that the financial return justifies their policy. The General Electric Company found that a costly research into the structure of the electric lamp repaid itself over and over again. The very important technical discoveries of Langmuir and Coolidge were consequent upon an attempt to find out what happened on the surfaces of the glass bulb and of the glowing filament. The point is that the electrical industry was not merely launched by a single discovery; it is continually guided, strengthened, and extended by unremitting research.

Consider the very active motor industry. The most important of all the problems connected with the internal combustion engine is that of the nature of the explosion, the effects of varying the mixture, the movement of the gas in the cylinder before the ignition, the actual occurrences at the moment of ignition, the movement of the subsequent explosion wave. The problems are exceedingly intricate. They have been and are the subject of intense research in various laboratories in this country. The research is new and the industry is new. The construction of the engine depends on the use of alloys possessing the most remarkable properties, all of which were practically unknown until recent researches of the metallurgists brought them to light. The motor-car is connected, too, with the laboratories in which chemistry and physics are applied to the study of rubber. Here again is a whole story in itself, which would tell of the work done on the intricate consequences of various kinds of mixings and of treatment, of the vulcanizing and of the use of "fillers." Not many know the story; they are only aware that motor-car tyres last longer than was once the case.

The aeroplane, like the motor-car, has become possible because of the advent of the internal combustion engine; but it has a unique feature—its element of romance, its motion through the air. The laws of aero-dynamics are becoming better known, and with every advance in their knowledge the efficiency of the aeroplane increases. Their intricacy is gradually resolved, but the process demands, in the first place, mathematical skill, and in the second the fascinating that is carried on in the wind channels of our laboratories. On this splendid work the progress of the aeroplane depends. I saw not long ago in a London shop window a coloured print of a flying machine. From across the street it might easily have been taken for a drawing of a modern aeroplane; a closer view showed still the same general spread of wings, the same whirling screws, the same discharge from the exhaust, a boat not at all untrue to modern design, and wheels to bear it when on land. Moreover, the proportions were quite familiar. Yet the date was 1843. For all its resemblance to the modern aeroplane, how far it was from flying not only in time but also in capacity! The difference between old and new in the form and materials of the wings may not be obvious to the casual observer, but in reality a wealth of trial and calculation lies between the crude projections of the old invention and the modern machine that flies. The turn of a line in the sectional outline of the wing may make the difference between success and failure, though it is only one of innumerable and equally essential details. The scientific worker grasps the meaning of that turn, and the airman tries it out; and that is the combination which brings success at last. The point is that the construction of the flying machine is a new industry based directly on knowledge recently acquired in the laboratories and continually growing under laboratory experiment. Everything depends on this careful, well-informed concentration on essential details.

If we enter the chemical province we find that there are thriving industries based on recent scientific discovery; instances at least as remarkable as those possessing a more physical basis. The chemical industries are so many and various that even a brief summary is beyond me; yet the whole of them are of comparatively recent origin. Quantitative chemistry is little more than a century old. And the more modern and more vigorous of the chemical industries depend on very recent chemical research, as, for example, those which deal with dyes, explosives, fertilizers, rubber, artificial silk, and many other things. It is the same story: the craft is based on science, and in this case very obviously so. Chemical industries are based on scientific discovery, and lean on it the whole time.

It is natural to compare the condition of the newer industries with the older industries known as basic because they have long constituted by far the major portion of the country's industrial effort and are still pre-eminent: coal and steel, cotton and wool. In some of these industries there is serious depression. What has the fact to do with science and scientific research?

It is obvious that we cannot say of any industry or craft that its condition depends only on scientific knowledge and imagination. The difficulties of the coal trade are due in large part to the powerful cause of competition. We had a good start in the knowledge of the existence of our coal deposits and in the practice of working them, in the means of distributing coal, and in methods of making use of it. We reaped our harvest. But as time went on other nations gathered way in pursuit of us; they also found coal deposits, they learnt how to work them, and could even improve on our practice because they could profit by our mistakes to a greater extent than we ourselves. They had not so much old machinery to scrap. Means of transit were developed in these countries; in fact we helped to develop them, as also the industries that used the coal. Such conditions must inevitably have tended to diminish our lead. The war acted suddenly and violently in the same direction. It is reasonable, though deplorable, that the industry should find itself in difficulties. The situation is not wholly irremediable, though the older conditions can never completely return. But at least a partial retrievement is possible, and we know that various research organizations, some instituted by the State and some due to private enterprise, are grappling with the question involved. It is deeply interesting to see in what way the necessary efforts are being made, and indeed must be made.

Now, whatever is done, and in whatever way it is done, the results of such endeavour, whether related to the coal or to any other industry depend on those relations between craftsmanship and science which I have been trying to define. I would now consider these relations from one or two separate points of view. In the first instance let me say a word concerning the general connection between science and that condition in industry which is known as mass production.

It must always be the aim of an industrial organization to devise and set going one of those systems of manufacture on a large scale with which we have become familiar in recent years. With the aid of suitably designed machinery and methods, great numbers or quantities of some article in general demand can be produced at a comparatively small running cost. Generally, however, the initial cost is heavy, for the designing of the machinery and the planning of the methods call for great experience and skill, and they demand much time spent in the acquirement of the necessary knowledge and its utilization in design. Once the process is under way it may be possible, and it seems to happen on a sufficiently attractive number of occasions, that a smooth and peaceful running of the machinery brings in the wished-for returns. But every such phase of production comes to a natural end. An improved process is devised, and the new displaces the old. Or it may be a factory is set up in another country where labourers can be hired more cheaply; they may be intrinsically inferior, but that will not matter if they can be drilled into the mechanical process; and, as long as the machine runs true, the standard will not fall below a certain value. The event is in accord with expectation because men will always try to improve their productivity by the use of new knowledge or more favourable conditions, so that those who fail to recognize the principle will be left behind by those who do not. The stereotyping of some process can be fruitful only for its allotted time. Mass production is in its way splendid, ministering to the necessities and conveniences of many who must otherwise have gone without. But if it is brought to such a pitch that its processes call for little intelligence in their working, then cheap people of little intelligence will be found, in the end, to be in charge.

The relation of science to mass production is therefore both that of builder and that of destroyer. Mass productions are temporary lulls in the movement of imagination and knowledge. Much skill and thought and care may be required to arrange for one of those quiet and profitable times; the machine is set going and for a while goes by itself. But new applications of scientific knowledge, new ideas, new processes, new machines must always be in preparation. In the parks the gardeners are always nursing fresh plants to take the place of the old, and preparing them for their useful time of flowering. And so we see the meaning of the various research organizations which have been set up in the basic industries, such as the Fuel Research Board, the Cotton, the Woollen and the Silk Research Associations, the research laboratories of the steel masters at Sheffield. Much of our hope for the future is built upon their work.

If craftsmanship, to fulfil its task of providing for the people, must be continually improving its processes, then the nation that is to be successful must possess the means and the will to improve, and here we come, I think, to a notable point. May it not be said that in this country the means exist even to a remarkable degree? Our craftsmen as a whole, including all grades, are possessed of qualities, intelligence, skill, accuracy, and so on, which make improvement possible. How could our enterprises in the past have been so often successful if this had not been so? How can we be succeeding so well in respect to the new industries of the present if the capacity is not there?

Should it not, therefore, be our policy to take advantage of our country's qualities by continually seeking for fresh industries or fresh adaptations of the old? We should not surely cling unduly to older activities when they have reached the stage in which many others have learnt to do them with equal efficiency, and when we can go on to something new and, it may be, more difficult. We can, of course, bolster up old industries by political methods, and I have no wish to decry such methods as always incorrect. But clearly the best protection of all is the knowledge and skill which can enable us to produce what others must ask us for because they cannot so well make it themselves.

These considerations lead naturally to a second aspect of the relations between craftsmanship and science. The improvement of craftsmanship depends in large part on the absorption and adaptation of scientific discovery. How is the process to be encouraged?

We here come to a point which must be emphasized with all possible vigour, because its importance is not always realized. Scientific knowledge and experience, if they are to be of full service, must be in direct practical contact with the problem that is to be solved. This must be clear to every one of us from actual experience. If you have expert knowledge on any subject and your advice is asked, your first instinct is, as you all know, to ask to be allowed to see for yourself. It is only when all the circumstances are clear to you in their relation to the difficulty that the solution is likely to suggest itself. And it may take much watching and patient observation before you are successful. It is the combination of actual experience with scientific knowledge that is essential. As the principle is so fundamental, I may be allowed to illustrate it by an actual experience :—

It was in the early years of the war that a body of young scientific students from our Universities was assembled for the purpose of testing on the battlefield the value of such methods of locating enemy guns as were already known. In their mutual discussions and considerations it became clear to them that the great desideratum was a method of measuring very exactly the time of arrival of the air pulse, due to the discharge of the gun, at various stations in their own lines. If the relative positions of the stations were accurately known it would then become a matter of calculation to find the gun position. But the pulse was very feeble: how could it be registered? Various methods were considered, and among them was one which no doubt seemed far-fetched and unlikely to be successful. A fine wire is made to carry an electric current by which it is heated. If it is chilled, for example, by a puff of cold air, the resistance to the passage of the current increases, and this is an effect which can be measured if it is large enough. If, then, the hot wire could be made to register the arrival of the air pulse from the gun a solution of the problem was in hand. No doubt this method occurred to several members of the company; it was certainly turned over in the mind of one of them who had had considerable experience of these fine heated wires. They had been in use about thirty years, having been employed for the measurement of temperature in many circumstances where their peculiar characteristics gave them the supremacy over thermometers of the ordinary form. But, and this was the important point, was it to be expected that the effect, though it must be there, would be big enough to see? Could the faint impulse from a gun miles away produce an obvious chill in a hot wire? On first thoughts it did not seem likely, and the suggestion lay in abeyance.

But it happened that one summer morning an enemy aeroplane came over at daybreak on a patrolling expedition. The officer of whom I have spoken lay awake in his bunk listening to the discharges of the anti-aircraft guns and the more distant explosions of their shells. Every now and then a faint whistling sound seemed to be connected with the louder sounds. The wall of the hut was of felt; it was in poor condition and there were tiny rents close to his head as he lay. The gun pulses made a feeble sound as they came through. This set the officer thinking: if the pulse was strong enough to make a sound, it might be strong enough to chill a hot wire perceptibly. So the method was proposed to the company as worth trying. It was tried, and proved to be a complete success. The sound ranging of the British armies was based upon it, with results which have already been described and are fairly well known.

It is clear that the all-important suggestion could have been made only by a man who had had scientific training and experience. That is one point of the first significance. The second is that it could have been made only by such a man actually on the spot. He could not have realized the details of the problem if he had been anywhere else.

It is worth while to consider this last point a little more closely. What precisely was the difficulty which could be resolved only by a combination of knowledge and of being on the spot? It was really the difficulty of making a true estimation of quantities. It was a question of magnitudes and measurements. Any one possessed of scientific knowledge could have said, if asked, that a gun must make an air pulse, and that an air pulse would chill a hot wire to an extent which might or might not be measurable. But there is all the difference in the world between such vague general knowledge on the one hand, and, on the other, the realization that such a method is likely to work and give the desired result. It is the difference which so often escapes attention, but every one of experience knows that it is to be reckoned among the essentials. It is so easy to talk generalities or to think of them, and so difficult to get down to the details which make the effort a success. It may be the last little adjustment of magnitudes that turns the scale, and the last step the one that counts.

Are we, then, in this country, putting our scientific knowledge into the position where it is really effective? I would draw your attention to a most interesting and important movement which is attaining a notable magnitude.

A new class of worker is growing up among us consisting of the men engaged in research associations and industrial research laboratories throughout the country. We must place a high value on their services, for they are actually and personally bringing back with them into craftsmanship the scientific knowledge which is one of its essentials. They bring the interest and the outlook of scientific enquiry into touch with both employer and employed, and I cannot but think that they may be to some extent the flux that will make them run together. For they can speak with the employer as men also trained in University and College, exchanging thought with ease and accuracy. And, at the same time, they are fellow-workers with those in the shops and can bring back there some of the interest and enthusiasm which spring from the understanding of purposes and methods. It is to be remembered always that personal contact has, on the whole, thanks to the better qualities in human nature, a marvellous effect in smoothing out differences. I do not think it is unduly optimistic to welcome the growth of this new type of industrial worker because it can, being in personal intercourse with both capital and labour, supply to each a new outlook on their whole enterprise, especially as that outlook is naturally illuminating and suggestive. For, after all, this is but going back to first conditions. The primitive craftsman has been replaced by separate persons or groups of persons who have slipped away from each other almost without our realizing the fact. In the most recent times the separation has become more obvious and more dangerous, and that is why in so many directions efforts are being made to stem it. Can it be good that the workman has a part demanding little intelligence, merely the capacity to repeat? Can it be expedient that mere manipulation should be left in the shop, while design and imagination have gone into the drawing office and shut the door behind them? Can it be right that the factory directorate should not be in immediate contact with the vast body of scientific knowledge?

The present number of industrial research workers is relatively small; it seems likely to increase, however, in proportion to the extent to which the province of science is better understood. The better understanding I think of as manifesting in the first place in industry itself. I am sure that here it is happily on the increase. There is also a broader view to be taken. There is a public estimation of the value of any calling which affects the numbers and the quality of those who respond.

I doubt if there is in the first place sufficient appreciation of the interests and rewards in the life of a student of industrial research. The pioneers have suffered unnecessary restrictions and discouragements, but their followers will be in better case. Surely it does not need much imagination to realize the splendid side of such work? The succession of fresh difficulties to be overcome, and of new and interesting views into the nature of things and ways of the world; the unforeseen value of results, sometimes an immediate prize, sometimes the clearing of an obstacle in a manufacturing process, never less than the discovery of facts which may some day be of use; the personal association with a living enterprise and with the human spirit behind it. And when it is realized that this kind of work is wanted badly, that it is really serviceable to the community, that there is opportunity for devotion, that it is in touch at once with human needs and with the furthest stretches of thought and imagination, it surely takes on to us the final touch of nobility.

We must remember also that the road of the student of science is still none too clear. The very methods of teaching science are a constant subject of discussion. I will say no more now than this: that the best methods must take time to elaborate, and cannot be expected to have arrived at their final form. The difficulty is increased by the fact that science itself grows rapidly, and the extent of its application is only now revealing itself. That the knowledge of the immensity of nature and the study of the natural laws have an educative value is well recognized. That science can be used as an educational drill is also known and made use of. But there still remains the human side: the continuous effect of the growth of knowledge upon thought and enterprise; the realization of the immense part that science is playing in modern life and is likely to go on playing. Education by scientific instruction is still apt to lack the comprehension of the human side, without which the class-room is a dull place.

There are even some who think that science is inhuman. They speak or write as if students of modern science would destroy reverence and faith. I do not know how that can be said of the student who stands daily in the presence of what seems to him to be infinite. Let us look at this point a little more closely.

The growth of knowledge never makes an old craft seem poor and negligible. On the contrary it often happens that under new light it grows in our interest and respect. Science lives on experiment; and if a tool or a process has gradually taken shape from the experience of centuries, science seizes on the results as those of an experiment of special value. She is not so foolish as to throw away that in which the slowly gathered wisdom of ages is stored. In this she is a conservative of conservatives.

What is true of a tool or process is true also of those formulæ in which growing science has tried to describe her discoveries. A new discovery seems at first sight to make an old hypothesis or definition become obsolete. The words cannot be stretched to cover a wider meaning. By no means, however, is that which is old to be thrown away; it has been the best possible attempt to express what was understood at the time when it was formed. The new is to be preferred for its better ability to contain the results of a wider experience. But in its time it will also be put aside. It is by a series of successive steps that we approach the truth: each step reached with the help of that which preceded it.

Nothing in the progress of science, and more particularly of modern science, is so impressive as the growing appreciation of the immensity of what awaits discovery, and the contrasted feebleness of our ability to put into words even so much as we already dimly apprehend. Let me take an example from the world of the physical sciences. There is a problem of which the minds of physicists have been full in recent years. The nineteenth-century theory of radiation asks us to look on light as a series of waves in an all-pervading ether. The theory has been marvellously successful, and the great advances of nineteenth-century physics were largely based upon it. It can satisfy the fundamental test of all theories, for it can predict the occurrence of effects which can be tested by experiment and found to be correct. There is no question of its truth in the ordinary sense.

In the last twenty or thirty years a vast new field of optical research has been opened up, and among the curious things we have found is the fact that light has the properties of a stream of very minute particles. Only on that hypothesis can many experimental facts be explained. A wave theory is of no use in the newer field. How are the two views to be reconciled? How can anything be at once a wave and a particle? I do not believe that I am unjust to any existing thinker if I say that no one yet has bridged the gap. Some of you who were present at the Liverpool meeting may remember that Bohr—one of the leading physicists of the world—doubted if the human mind was yet sufficiently developed to the stage in which it would be able to grasp the whole explanation. It may be a step forward to say, as we have been saying vaguely for some years, that both theories are true, that there are corpuscles and there are waves, and that the former are actually responsible for the transference of energy in light and heat, and for making us see; while the latter guide the former on their way. This is going back to Newton, who expressed ideas of this kind in his *Opticks*, though he was careful to add that they were no more than a suggestion.

We are here face to face with a strange problem. We know that there must be a reconcilement of our contradictory experiments; it is surely our conceptions of the truth which are at fault, though each conception seems valid and proved. There must be a truth which is greater than any of our descriptions of it. Here is an actual case where the human mind is brought face to face with its own defects. What can we do? What do we do? As physicists we use either hypothesis according to the range of experiences that we wish to consider. To repeat a phrase which I employed a few years ago in addressing a University audience familiar with lecture time-tables: on Mondays, Wednesdays, and Fridays we adopt the one hypothesis; on Tuesdays, Thursdays, and Saturdays the other. We know that we cannot be seeing clearly and fully in either case, but are perfectly content to work and wait for the complete understanding.

And when we look back over the two centuries or so during which scientific men have tried systematically to solve the riddle of light, or even go further back to the surmisings of philosophers of still older time, we see that every conscientious attempt has made some approach to the goal. The theories of one time are supplanted by those of a succeeding time, and those again yield to something more like the first. But it is no idle series of changes, of vagaries of whimsical fashion; it is growth. The older never becomes invalid, and the new respects the old because that is the case.

Surely it is the same in regard to less material affairs. The scientific worker is the last man in the world to throw away hastily an old faith or convention, or to think that discovery must bring contempt on tradition.

There is a curious parallelism here to a relation between science and industry of which I have already spoken. Just as any particular case of mass production can be regarded as a temporary condition which the growth of knowledge brings about, and in the end supersedes, so also it may be said of any law or rule or convention or definition that knowledge is both the parent and eventually the destroyer. Time devours his own children. Even if a statement retains its outward form, its contents change with the meanings attached to its terms: and change moreover in different directions when used by different people, so that constant re-definition is necessary. How much more is this the case when the contents themselves have to be added to. The distinction between truth itself and attempts to embody it in words is so constantly forced upon the student of science as to give his statements on all matters a characteristic form and expression. And this is, I think, one of the reasons why men are often needlessly alarmed by the new announcements of science and think they are subversive of that which has been proved by time.

To this consideration I may add yet one more, which may be illustrated by the same analogy. Scientific research in the laboratory is based on simple relations between cause and effect in the natural world. These have at times been adopted, many of us would say wrongly, as the main principle of a mechanistic theory of the universe. That relation holds in our experimental work; and as long as it does so we avail ourselves of it, necessarily and with right. But just as in the case of research into the properties of radiation we use a corpuscular theory or a wave theory according to the needs of the moment, the two theories being actually incompatible to our minds in their present development, so the use of a mechanistic theory in the laboratory does not imply that it represents all that the human mind can use or grasp on other occasions, in present or in future times.

The proper employment of scientific research is so necessary to our welfare that we cannot afford to allow misconceptions to hinder it; and the worst of all are those which would suppose it to contradict the highest aims. Science, as a young friend said to me not long ago, is not setting forth to destroy the soul of the nation, but to keep body and soul together.

And some perhaps might say that in considering science in relation to craftsmanship I am pressing the less noble view; that I am not considering knowledge as its own end. It is said that uselessness in science is a virtue. The accusation is a little obscure because it may justly be said that knowledge is never useless. If I have thought of science in relation to craftsmanship it is because I have tried to set out the vast importance of what craftsmanship means and stands for. I have not forgotten that there are other aspects of the enquiry into the truths of Nature. Indeed, I could not carry out the lesser task without considering the whole meaning of science. And no clear line can be drawn between pure science and applied science: they are but two stages of development, two phases which melt into one another, and either loses virtue if dissociated from the other. The dual relation is common to many human activities and has been expressed in many ways. Long ago it was said in terms which in their comprehensiveness include all the aspirations of the searcher after knowledge: "Thou shalt love the Lord thy God with all thy heart and with all thy soul and with all thy strength"; and "Thou shalt love thy neighbour as thyself." In the old story every listener, from whatever country he came—Parthians and Medes, Cretans and Arabians—heard the message in his own tongue. A great saying speaks to every man in the language which he understands. To the student of science the words mean that he is to put his whole heart into his work, believing that in some way which he cannot fully comprehend it is all worth while, and that every straining to understand his surroundings is right and good; and, further, that in that way he can learn to be of use to his fellow-men.

II

The Influence of Learned Societies on the Development of England[1]

I AM a very proud person to-night. I am for this evening the spokesman of a great Society, trying to contribute something to the part which such a society as yours plays in the world. And it is because that part is of such real importance that I feel deeply both the honour which you have done me in electing me to be your President and the responsibility which the position entails. Many societies like this Institute have been founded, especially within the last few centuries, and have grown to great things. Some have represented the aspiration of nations, like the Royal Society of London or the Académie of France or the Lincei of Italy, and some have been built on more circumscribed foundations, like those of Manchester or of your own Birmingham, or other great cities of the Empire, and of other countries. But all have had this in common, to increase knowledge and the appreciation of its power, and to direct the gathering stream to true and honourable purposes. It is a noble task, which has at all times attracted to its service men of single purpose who were profoundly interested in the world about them, who delighted in trying to grasp what they could of its methods of working, and who, I am persuaded, had always the hope that what they did might be of service to their fellow-men.

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[1] An address delivered before the Birmingham and Midland Institute on October 21, 1926.

When men have gathered together for such objects their deliberations and writings have always represented the thought movements of their time. This is true of all associations of the kind, but I am speaking to-night of those that have been formed for the promotion of natural knowledge. For this reason alone it is of great interest to refer back to the early records, in order to see what the thinkers of those times had in their minds and what they hoped and worked for. And not only were their ponderings indicative of the gradual unfolding of contemporary thought, but also they were so coloured by the actions of their times as to make vivid additions to the materials of history. As we know, for it has been thoroughly impressed upon our minds of recent years, there is more in history than the records of wars and treaties and of the risings and fallings of dynasties. The story is to be told also of the growth of man's mind, of his religious feelings, of his appreciation of beautiful things, of his technical skill, and lastly of his knowledge of the material world in which he lives, which knowledge not only affects deeply his other learning, but also gives him the power of making good use of it. There is a fascination, therefore, in the study of the records of these learned societies. Nothing could be more absurd than to suppose that they are remote from the happenings of our lives, even from the simplest of them. Not only can we trace the consequences of those old deliberations in the practice of those times and the times that have followed up till now, but also, as I have just said in other words, we find the reverse influence, that is to say, the bending of thought and enquiry into directions which were enforced by the difficulties and the necessities of the period.

Let me take the early work of the Royal Society as an example of my meaning. Let us imagine ourselves taking down from its honoured place on the library shelf the first volume of the Transactions of the Society, printed in 1665, and as we carefully turn over the old pages let us observe what the founders of the Society talked to each other about. The very first paper is an account of the Improvement of Optick Glasses in Rome. This brings at once to our minds the fact that the uses of lenses for both telescopic and microscopic vision were then beginning to be appreciated at their true value. Men were deeply interested in their new power of penetrating the heavens. Galileo had made his telescope, Newton was working at his; marvellous facts were coming to light about the sun, the moon, and the stars: Saturn had a ring, Jupiter had moons which revolved about it in an amazing regularity. And yet there was a curious irregularity within that regularity of the moons of Jupiter; predictions which the astronomers ventured to found on their new measurements were all too early for one half of the year and too late for the other. Then the meaning of this unexpected observation was suddenly realized. It meant that light which brought the intelligence of the movements of the satellites took time to travel, and so the news arrived too early when the earth and Jupiter were on the same side of the sun and at their nearest, while it arrived persistently late when the light had to cross the width of the orbit of the earth. What tremendous ideas these old thinkers were grasping! With what awe they must have realized that the mind of man might see the order of the universe! And how they must have struggled with the technique of the telescope on which the enlargement of their vision depended! So the first of the papers printed by the Royal Society deals with the Improvement of Optick

Glasses in Rome. Italy, we remind ourselves, was the country of Galileo, who first put optick glasses together to show us the way through the maze of stars.

The very next number of the Transactions, dated April 3rd, 1665--the first was dated March 6th, 1664-5 —contains an account of Hooke's *Micrographie.* What more perfect antithesis to the first paper could have been achieved? The *Micrographie* is also on our library shelf, and we can take it down and glance at one after another of its short but numerous chapters. The first Royal Society paper touched on the use of the lens to give vision of the great things of the universe; this paper talks of Hooke's parallel enquiry into the infinitely small. Hooke had made himself a microscope, but was not the first to design one; that had been done in Italy half a century before. But he was one of the first to undertake a detailed examination of the minute things of the earth which had hitherto escaped observation because they were too small to see. This also was a new realm of interest and importance. So Hooke initiated the great enquiry into all those bodies which are minute in dimensions only and are huge in their collective influence. He was the precursor of all those who since then have used the microscope to increase their knowledge; and such men have been students of every branch of science and of every application. Botany and biology, bacteriology and medicine, physics and chemistry, metallurgy and all the industries have depended on the microscope for their progress. The paper reflects the interest which the men of the time took in this further use of lenses and their combinations. They could have had no vision, of course, of all that they and their successors would achieve by means of their optick glasses.

Each chapter of Hooke's book deals with his examination of some one thing—a spider's web, a needle point, a seed, and so on. And each is accompanied by very shrewd remarks on what his microscope had shown him. I will give you one curious extract from these comments of his, although I have already drawn attention to it in a Christmas lecture at the Royal Institution. He is talking of "fine waled silk or taffety," and at the end of his description of its appearance under the microscope he goes on to say:

> "A pretty kinde of artificial Stuff I have seen, looking almost like transparent Parchment, Horn, or Ising-glass, and perhaps some such thing it may be made of, which being transparent, and of a glutinous nature, and easily mollified by keeping in water, as I found upon trial, had imbib'd, and did remain ting'd with a great variety of very vivid colours, and to the naked eye, it look'd very like the substance of the Silk. And I have often thought, that probably there might be a way found out, to make an artificial glutinous Excrement, or whatever other substance it be out of which the Silk-worm wire-draws his clew. If such a composition were found, it were certainly an easie matter to find very quick ways of drawing it out into small wires for use. I need not mention the use of such an Invention, nor the benefit that is likely to accrue to the finder, they being sufficiently obvious. This hint therefore may, I hope, give some Ingenious inquisitive Person an occasion of making some trials, which if successfull, I have my aim, and I suppose he will have no occasion to be displeas'd."

Artificial silk is now so important an item of manufacture, in this country especially, that it is interesting to see how Hooke, seeing for the first time the details of nature's instrument for making the real thing, should have imagined the artificial manufacture and grasped its financial importance.

The third number of this first volume of the Transactions (May 8th, 1665) gives an account of a work by Mr. Boyle on "The Experimental History of Cold." There is indeed a preliminary notice in the first number, but it is there explained that the treatise had been delayed, because, curiously enough, the press had been stopped by the extremity of the late frost. The name of Boyle at once conjures up the vision of all that he did to extend our knowledge of the laws of gases. Five years before the publication of these papers we find his name in the Records of the Royal Society, as keenly interested in the promotion of experiments thereon.

It has to be remembered that at the time when Boyle was carrying on his researches the pressure of the air, or rather the unexpected magnitude of this pressure, was one of the new marvels of acquired knowledge. The natural philosophers of all countries were greatly taken with it: as was very natural. It was a tremendous idea that the surrounding air, which moves so easily and impedes us so little, exerts so great a force that the aggregate pressure on the human body is of the order of fifteen tons. The famous experiment of Torricelli, in which he made the first barometer and so proved the magnitude of the atmospheric pressure, was the step of a great pioneer, and led the way to developments of which the enumeration would fill volumes. We can imagine how his contemporaries heard of his experiment with astonishment and tried to repeat it. Pascal, the great French physicist and divine, had carried out his famous trial of the difference in the height of the barometer at the top and the bottom of the Puy de Dome, a high mountain in Auvergne. There was a difference of three inches in the height of the mercury, "which ravished us," so he says, "with admiration and astonishment." So the old idea that "nature abhorred a vacuum" disappeared, and was replaced by the understanding that the pressure of the air furnished the real explanation of many puzzling facts. Guericke, of Magdeburg, constructed a copper globe to which a pump had been attached: the globe was filled with water and then closed up except at its point of attachment to the pump. At first the piston moved easily, but later the strength of two men could hardly move it, when "suddenly with a loud clap, and to the terror of all," the sphere collapsed.

And in England, too, the new knowledge was keenly discussed. Boyle was one of a small committee, composed of Lord Viscount Brouncker, Mr. Boyle, Sir Robert Moray, Dr. Petty, and Mr. (Christopher) Wren, the very first committee which the Royal Society appointed for a scientific purpose, for it was constituted at the very meeting of the Society to which Sir Robert Moray brought word from the Court that the King approved the formation of the Society itself. In the terms of the reference they were to "prepare some questions in order to the tryal of the quicksilver experiment upon Teneriffe." And later on were "entered into the register-book of the Society the following questions propounded by the Lord Viscount Brouncker and Mr. Boyle, according to an order of the Society of the 5th of December, 1660, and agreed upon to be sent to Teneriffe."

There were twenty-two questions in the submission of the committee: and very shrewd indeed they were. It would take too long to quote them all; one or two will serve as examples. Let us remember that the underlying purpose of them all was to test various physical effects at different heights of the mountain, since, if the pressure of the atmosphere was a reality, differences in some of the effects might appear at different heights, though as yet it was uncertain which of the effects would be altered, and by how much. Here are a few :

> 1. " Try the quicksilver experiment at the top, and at several other ascents of the mountain ; and at the end of the experiment upon the top of the hill, lift out the tube from the restagnant quicksilver somewhat hastily, and observe if the remaining mercury be impelled with the usual force or not. And take by instrument, with what exactness may be, the true altitude of every place where the experiment is made ; and observe, at the same time, the temperature of the air, as to heat and cold, by a weather-glass ; and as to moisture and dryness, with an hydroscope ; and note what sense the experimenters have of the air at those times respectively.
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> 2. " Carry up bladders, some very little blown, some more, and others full blown ; and observe, how they alter upon the several ascents.
>
> 3. " Try by an hour-glass, whether a pendulum clock goes faster or slower on the top of the hill than below.
>
> 4. " Make the experiment of two flat polished marbles upon one another with a weight hanging at the lower, and carefully note the greatest weight that may be applied on the top of the hill, and also below.
>
> 5. " Try whether birds, that fly heavily, or others clogged with as much weight as they can well fly with below, can fly as well, better or worse above.
>
> 6. " Observe what alterations are to be found in

> living creatures, carried thither, both before and after feeding; and what the experimenters do find in themselves as to difficulty of breathing, faintness of spirit, inclination to vomit, giddiness, etc.
>
> 7. "Try to light a candle with a match, and fire some spirits of wine; and observe if they burn upon the top of the hill as well as below; and of what figures, colours, etc. the flames are."

Now it happened that at that time coal-mining in England was in a very bad way, though the difficulties which beset it were not the same as those which cause us so much perplexity now. The trouble then was that the mines were becoming water-logged. The miners in their pursuit of coal had penetrated so far into the earth that the cost of lifting the water was smothering the profits of the mines. The early times when men could lift the water by hand had long gone by; drainage was, of course, out of the question, since there were no cavities lower than the bottom of the mine into which the water might be drained. Even horse-power was becoming insufficient: water-power was not always to be had. All the coal-mining world was deeply concerned in finding some method of lifting the water from the flooded seams: in fact, the future of English industry was in the balance.

The result of these throes was the birth of the steam engine. The new ideas of the pressure of the air and the behaviour of gases and vapours which Torricelli and Pascal, Boyle and Hooke, and others, were so rapidly developing, were harnessed up to draw the coal-mining industry out of the mire. The action of the steam engine depends entirely on the laws of gases: its invention would have been impossible without some acquaintance with them. It was obviously because this new knowledge was in all learned countries being eagerly examined and extended that it was ready for use by Savery and Newcomen when they looked for a practical solution of the water problem. Nothing could have been simpler or more direct than the method which Savery proposed. There was to be a closed metal vessel containing only steam from which a pipe descended to the water some thirty feet below. The steam was to be condensed by pouring cold water over the vessel: whereupon the pressure of the atmosphere on the water below would force it to rise and fill the vessel. The water so raised was to be removed and the vessel refilled with steam, after which the cycle began again. Of course, the lift so obtained would necessarily be limited by the height to which atmospheric pressure can raise water: and in actual practice it was much less, even though Savery tried to use steam pressure to do some forcing as well. If the mine were a few hundred feet deep, quite a number of Savery's pumps would be wanted to act in series. This was impracticable, partly because the mines were sometimes fiery, and no furnace could be allowed within them. Newcomen's plan was much better. Pumps of the ordinary kind were already in common use in the mine, driven sometimes by horse-power, sometimes by water. Newcomen conceived the idea of using the condensation of steam, not to pull up the water directly, as Savery had suggested, but to pull down one end of the pump handle to the other end of which the pumps were attached. His engine was therefore built on the surface and joined up with the already existing pump system. Of course, the pump handle of ordinary use was replaced by the great beam which some of us can remember as still working in the old beam engine.

The connection of Newcomen's inventive work with the discussions of the Royal Society and other congregations of men interested in scientific enquiry appears to have been close indeed; for old writers tell us that Newcomen actually consulted Hooke when he was trying to develop his engine, and that Hooke wrote a set of notes for his guidance. It is asserted to be true by no less a man than Professor Robison, of Edinburgh, who wrote the article on the steam engine in an early nineteenth-century edition of the *Encyclopædia Britannica.* It would be delightful if the incident could be verified by the discovery of Hooke's notes, and it is not impossible that this may happen, for Robison's writings of a century ago suggest that they were then in existence.

We do not, however, need this confirmation to show that the pressure of the atmosphere and the laws of vapours were subjects of the day: we have ample evidence in the writings and records of the time. One odd little piece of testimony may be found in an entry made by Pepys in his diary (1st Feb., 1663), that he went to Whitehall, and there came in the King "laughing mightily at Gresham College"—meaning the Royal Society—"for spending time only in weighing of ayre." I have no doubt it did seem odd to many people that such trouble should be taken over so small a thing as the weight of a little air. But the experimenters saw more deeply than the casual observer. And we must not forget that Charles II himself was deeply impressed with the necessity of encouraging the advancement of knowledge. He himself founded the Royal Society in consequence of his belief in the work it could do, though he may have been amused at the direction which their investigations had taken in this particular instance.

How much has sprung from the association, on the one hand, of the work of the sixteenth-century philosophers on the laws of the air and other gases, and on the other hand the difficulties occasioned by the flooding of the mines, would take volumes of writing to describe. The steam engine alone, as one of the consequences, fills us with an overwhelming sense of magnitude. I must not pursue this line of thought any further: let us go back to our first volume of the Royal Society Transactions.

We have looked at the titles of three of the earliest papers: each one opens out a wide and interesting subject. If you can bear with these considerations a little longer, I will go on to a paper in the fourth number (June 5th, 1665). It is an article by Sir Robert Moray on Tides. I am afraid this might invite us to another excursion as far spread as those that have preceded it, but we must hold ourselves in check.

The flow of the tides was at that time a much-discussed subject, both for its connection with pure science and for most practical reasons. To take the latter first, we must remember that long voyages were now being made continually. Traffic with the Americas had become a regular thing, and the construction of ships was affected by its necessities. It was desirable that they should be made larger so as to withstand the ocean perils for long periods, and there was also the economical reason that larger cargoes could be carried. But larger ships could not enter the old harbours so easily as those of lighter draught: the time during which the water was deep enough was limited to a shorter period on each side of high water. Moreover, the bigger the ship, the less should it be kept idle. So it was very much to be desired that the times and the heights of the tides should be predicted, and for as long ahead as possible. Moray's paper is but one of a series of communications and investigations which were common at that time. A very important paper was published in the Transactions a few years later by the astronomer Flamsteed, which contained a table of the heights of the tides at London Bridge for 1684; previous tables had been liable to errors as great as two hours, and these were very much more accurate.

On the scientific side there was equal interest in such a paper as Sir Robert Moray's. The connection between the tides and the movements of the sun and the moon was just beginning to be understood, and all observations on actual movements were of value. Various hypotheses were put forward by different philosophers in the hope of establishing the direct connection: it was Newton who finally put the matter on a correct basis some twenty years later.

The discussions of the tides remind us of another of the great problems of the age which finds its place also in the discussions of the Society. It was the measurement of time. It is difficult to realize without some thinking about it what this question meant in those days. The same development of navigation which I have already mentioned, the initiation of long voyages across the Atlantic, made it an urgent matter to be able to find longitude with accuracy. Now the measurement of longitude depends on the knowledge of the time at two places: one of them the place of the navigator, the other some standard place of reference. The first of these can be achieved by simple measurements of the movement of the sun: when the sun is at its highest point above the horizon the time is noon. But how is the navigator to know the time at Greenwich or any other standard place? We have learnt since then that he should carry with him a watch or chronometer which is set by Greenwich time at the beginning of his voyage and is expected to keep that time until the voyage is over. As a matter of fact, the chronometer of sufficient accuracy was not made until a century had elapsed:

but it is interesting to find in the early records discussion of the pendulum and its possibilities. The pendulum was actually tried at sea, but was not successful. The problems of navigation were indeed of extraordinary importance. England had become a naval power: and her trade was conveyed largely by her own ships across the seas. We see the reflection of this in the discussions of the Royal Society: and we see the reflection of these discussions in the development of navigation.

Let me now make a last reference to one of the early papers in the Transactions—a paper dated July 3rd, 1665. It is also by Sir Robert Moray, and deals with mining at Liège. This brings up the great question of mine ventilation, which was also an urgent matter at that time; as it has been ever since. Choke damp or stythe was well known: fire damp was beginning to make itself felt, for many of the mines had penetrated to depths below the wet strata and had reached the dry seams in which the explosive methane was waiting for them. It will interest you, I believe, if I quote from a letter written by a Dr. Jessop, of Yorkshire, and published in the Royal Society Transactions for 1675. Apparently they had rough methods in those days for restoring to consciousness those who had been rendered insensible by choke damp:

> "There are four sorts common in these parts: The first is the Ordinary Sort, of which I need not say much, being known every where; the external signs of its approach are the Candles burning orbicular, and the flames lessening by degrees until it quite extinguish; the internal, shortness of breath. I never heard of any great inconvenience, which any one suffer'd by it, who escaped swooning. Those that swoon away, and escape an abso-

> lute suffocation, are at their first recovery tormented with violent Convulsions, the pain whereof, when they begin to recover their senses, causeth them to roar exceedingly. The ordinary remedy is to dig a hole in the earth, and lay them on their bellies, with their mouths in it; if that fail they run them full of good Ale; but if that fail, they conclude them desperate."

Moray's paper contains a woodcut of the system of ventilation which he is describing. It shows the cage for burning coals suspended in a built-up continuation of the upcast shaft; the system appears to have been more regularly employed in Belgium than in England at that date.

These early struggles with problems of ventilation were a serious matter to the coal-miners: and again, as showing the close connection between the needs of industry and the growth of natural knowledge, we find frequent references to the subject in the Royal Society discussions. In fact, the continual investigations of the laws of gases with which Boyle had so much to do bore directly upon it.

You may be inclined to think that I have made out too good a case for the philosophical discussions that resulted from the founding of the Royal Society. It may seem fortuitous that the first papers in the Transactions should be so intimately connected not only with the growth of knowledge along important lines, but also with the needs of the industries of England. But the fact remains that it was so; and I venture to think that there is really no matter of surprise in it. Men who are interested in the advance of science often find their materials in the workings of industry, just as the geologist finds his library in the quarry or the railway cutting or the mine, and just as chemistry grows on the consideration of questions of everyday life. It is natural that they should wish to take their part in the solution of problems that are troubling the nation, and that in doing so they should both give and take, help and be helped. Many of the other papers to be found in these early volumes are of less obvious importance: in fact, the juxtaposition of subjects seems sometimes ludicrous to us who look at them now; but when Mr. Oldenburg edited the papers of the first volume I dare say he saw nothing curious in the assortment. One of the first plates published in the Transactions illustrates the point very well. The first figure has already been mentioned: it is Moray's illustration of the ventilation of mines by fire. Alongside are two drawings of mining tools, also Moray's. One of them shows the tool used for drilling holes in which blasting gunpowder was to be placed, the other the form of self-acting wedge with which the hole was to be closed. Alongside these useful and no doubt informative drawings is a monstrous head which does not seem likely to lead anywhere. As we turn over the pages we find many titles which have a queer sound. "Part of a letter concerning a person who had a new set of teeth after eighty years of age, with some observation upon the virtues and properties of sugar." "An experiment of making cherry trees that have withered fruit to bear full and good fruit and of recovering the almost withered fruit." "Observations of milk found in the veins instead of blood." "The use of chicken incubators in Egypt." This last was contributed by the Professor of Astronomy at Oxford: what was he doing in that galley? Other titles suggest again the interest in everyday things. "A way of preserving ice and snow by chaff"—an early discussion of cold storage. The Earl Marshal of England writes on the splitting of rocks in Indian diamond mines by means of fire and water. And so on.

We have to bear in mind the peculiar circumstances of the period. The direct enquiry into nature and the recourse to experiments were more and more filling the interests of men, in place of the logical disquisitions of the school men. In fact, the old founders of the Royal Society were like boys let out of school: running out with shouts of delight to poke about here and there in the streams and the hedges, finding all sorts of interesting things and eager to show them to one another. Everything they picked up was not really a treasure, but they made an astonishingly large number of important discoveries. And we are all children still, in this respect, and very fortunately so. This Institute over which I have the honour to preside to-night is itself a witness to the happy maintenance of the same enquiring spirit. For what other purpose do you exist than to fulfil some of the functions which were the first objectives of the old Royal Society founders? You wish to encourage the healthy desire to extend knowledge, and you have developed the methods of doing so. You have specialized on one of the objects of the old Society.

In the 250 years that have gone by since Charles II gave body to the aspirations of some of his influential and learned subjects, many societies have been founded in this country which have resembled the premier Society more or less closely. The limits of the cultivated ground have been extended, many more workers are upon it, and various methods of cultivation have been and are being tried.

The Royal Institution of Great Britain to which I am attached is an interesting and unique example of the extension of which I speak. It was an attempt to break new ground, which in the first instance came to grief and was afterwards turned in a new direction with ultimate success. Rumford, to whom we owe the existence of the Institution, and his associates were filled with the idea of bringing together under one roof workmen and employers and scientific enquirers to their mutual benefit. Workmen were engaged on their trades in the Institution itself : and the others were brought up to them in the hope that some useful fusion would take place. But this first attempt at organized combination of technical instruction and research failed in its purpose. Too great a gap divided one section from another : much experience had yet to be acquired before the connections could be smoothed down and the modern technical school and the modern research association become possible. Even now, as many of us are aware, we are far from perfection in these matters, although great and most valuable progress has been made.

Then it was that Humphry Davy swung the energies of the Royal Institution into a new direction. It became more like the original Royal Society, inasmuch as the connection between knowledge, craftsmanship, and finance was not to be made prominently and rigidly the purpose of the Institution. The pursuit of knowledge was to be maintained with all vigour, but the Institution was to be as the old Royal Society had been from the outset, free from any forced connection with industry. The connection was to be an *entente cordiale* rather than a rigid alliance. And that plan succeeded admirably. For the *entente* between industry and the growth of knowledge is most natural and easy : it is of the utmost importance to both. I think our consideration of the old work of the Royal Society gives us a clear illustration of that. But, as we all know, rigid alliances are not always so easy to contrive successfully, though sometimes they are necessities.

It is very interesting to observe that the new plan adopted at Davy's suggestion for the work of the Royal Institution involved the maintenance of a research staff. The Royal Society had something of this kind at one time: assistants were maintained whose duty it was to prepare experiments to be shown at the meetings of the Society. Hooke and Papin were so engaged. But the practice fell into disuse, and the Society has no laboratory. The Institution, on the other hand, made much of research work in its own laboratories, and the success of the plan is one of the most startling facts in the history of the development of scientific knowledge in England. It is doubtful whether any single building in the world can claim to have been the birthplace of so many discoveries of first-class importance. Davy, Faraday, Tyndall, and Dewar spent there the working periods of their lives: there is no need to set down the sum-total of their achievements.

The Royal Institution, like the Royal Society, is a private association, and the only qualification demanded of those who would join it is that its members shall be interested in science, to the advancement of which it is devoted. The Institution gives courses of lectures on all subjects, and maintains a catholic library: but its researches are confined to physics and chemistry. It has, you see, the same objects and in some ways the same procedure as yourselves: only in library and laboratories does it differ materially.

We may regard all these societies for the advancement of knowledge in one whole, thinking of them as an expression of one side of our national character and ideals. The interest in knowledge and its advances: the delight in seeing an ordered system unfold itself:

even the consciousness that the delight is perpetual and that we shall never come to a full understanding of all the surrounding wonders, all this is good and important. The craving is inborn, and its satisfaction is a fair object of desire. It is a first reason for the existence of our societies. Even if we are a society of listeners only, that is so much to the good. Societies such as the Royal Society and the Royal Institution have tried to do more. In the one case, the members have themselves worked to increase the bounds of knowledge, and in the other have maintained an equipment for the purpose. I might have spoken of other associations with which we are familiar: some of them only of recent foundation, but I have referred principally to these two because they are both so well known and both show so clearly by their accomplishments how much such association means to science and to industry alike.

The work of our societies is by no means completed. It is needed now as much as ever, and indeed more than ever. For we are all well aware of the difficulties of these times. Forty millions or so of people try to live in these islands. A century ago there were but five millions. Was the country empty at that time? Not so; it was full. The capacity of a country is not measured by its area, but by the amount of food and other necessaries which can be produced within it or imported from outside. A long time ago we could feed ourselves. There is a set of ancient cookery books on one of the shelves of the Royal Institution which not long ago I had the curiosity to glance through. The feature that amazes one is the profusion of food that was thought suitable to each meal: and the panegyrics in the preface on the richness of England in fish, flesh, and fowl for the use of its inhabitants. The balance has been greatly disturbed since then! We must buy food, and we must pay a price for it. That price is the work of our hands. And how can our hands make that which is acceptable to other countries unless our heads direct them? Other nations can design and make objects to satisfy their own needs, to a greater or less extent. We must, of course, be able to make things so desirable, so easily purchased, and so conveniently obtained that what we make is accepted in exchange for the food and other necessaries which we do not make ourselves. All this is very elementary economics, of course. But my point in trying to tell you of the work of our societies in days gone by and in our own is to make clear the close and inseparable connection between the growth of knowledge and the work of the nation. The discovery of the pressure of the air and the laws of gases saved the coal-mining industry two hundred and fifty years ago. So if we are to overcome the difficulties which again in these times press heavily upon us, if we are to find bread for our temporarily overgrown family, and to avoid the more drastic means which Nature is apt to employ in order to restore the balance between population and production, we must advance knowledge by all means in our power, so that we may provide a reservoir from which may flow the stream upon which the labours of the nation must depend for freshness and growth. For that end your Institute can and does play its part.

III

Research Work and its Applications[1]

RESEARCH is a word that is much used nowadays: especially, we may perhaps say, in consequence of the tremendous applications of science during the years of the War. There is a conviction that we ought as a nation to take more trouble about our research work and put it on a stronger foundation. The very existence of a Department of Scientific and Industrial Research, with power to allot large sums of money to the encouragement of research in promising directions, is a witness to the firmness with which that conviction is held on the part of Government. The various Industrial Research Associations which have been formed are breaking new ground, and some at least are going to reap a harvest. The fighting services have each of them, Army, Navy, and Air Force, well-established research departments, doing fine work Medical research is eagerly promoted, though, of course, the possibilities seem so great that it is easy to be impatient with the money and time devoted to it. In British Universities and Technical Schools the capacity for research is, as we all know, a test of constant application to candidates for teaching positions, and to students seeking the better classes of degree. It is all good healthy movement. Let me try to show what we are doing, and to bring our main aims into focus. In what way do we hope to benefit by research?

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[1] An address delivered at the Sir John Cass Technical Institute on January 30, 1924.

Let us begin with the work done by teachers and students in Technical Institutes. Why do we encourage the student to do research work at all? To put a very practical question, Why does a student stand a better chance of preferment if he has read a paper before some scientific society? We should answer, I think, that his research work is a guarantee that he possesses something more than the capacity to learn from books: a something which is of urgent importance to himself and to others. It implies a training of a special character. Research work brings out a man's self-reliance and proves his capacity to march by himself.

A good research student is like a fire which needs but the match to start it. It is a discipline to put the text-book to one side and to get out further knowledge by one's own effort. It teaches the student how to value evidence; how to read with discretion, since he must weigh what others have done before he uses the previous knowledge as a foundation for his own advances. He learns to meet disappointment, to realize how little he can do in a day, and that weeks or months may go by without obvious progress. It is strange to discover that he must spend so much time on small things, that he must wait a week before he has succeeded in stopping a small leak, or go himself to buy some trivial thing, or spend weary hours in the adjustment of an instrument which in the end he learns to put straight in a moment. There is so much little work to be done before the good observations come; it may be that weeks are spent in preparation and five minutes in making the actual measurement. It is all very humiliating; and the blunders one makes are very foolish; and the one redeeming feature is that in its apparent perversity it is like every other piece of real work. Research is rather like playing against bogey at golf: Nature never has any weakness of which advantage may be taken; there is no hole to be won by bad play because our opponent plays worse. Yet research is very human, for the researcher finds himself one of a company who have in their turn striven and denied themselves, very happily; and have handed on their experience to those who take up the quest where they have left it.

It is, as I have said, a great discipline; and there is always the hope before every student that he may contribute something to the total of human knowledge. Perhaps the hope is not so often reached as it might be, but that does not mean that the work has been done in vain: a thousand times, no. It is a remarkable fact that if a man tries to set down on paper, in line or in colour, that which he sees in Nature, his own vision of what is beautiful is quickened. The pencil teaches him the beauty of line, and the brush opens his eyes to all sorts of delicate colour schemes which he never saw before. It does not matter if his efforts are a bitter disappointment to himself, and he need not show them to any one else. Similarly, the man who strives to understand the workings of Nature by experiment which may make him feel very feeble and stupid, is paid by his discovery of a richer world. There is a fellowship between all who have tried to understand, which enables the worker in one field to have a welcome power of appreciation of the work of others. He gains not only in the richness of appreciation of what is beautiful and interesting, but also in the power of making friends.

And yet, we may say, these are not the things which we have most in mind when we devote the national funds to research. We expect results which will be of benefit to us all. We realize that activities of to-day are the consequence of discoveries of the past: that, for example, Faraday's discovery of electro-magnetic induction laid the foundation of all the electric development of our time; that Pasteur's researches in bacteriology gave us new insight into the meaning of disease and new powers to fight it; and that the work of the organic chemist has given us a host of new colours for our pleasure. We know that in a thousand ways the results of research have added to our riches, removed our disabilities, and eased our pain.

If science has also been turned to sad purposes, as in the poison gas, we can say justly that, for one life it has been made to take by evil use, it has saved a hundred in the hands of those fit to employ it. We cannot escape from the need to defend our country and establish her in the world: it is true, however sad it may be, that if we do not develop research among us so that we may improve our fighting capacity, then other nations can bring us to defeat and shame. Further, if we fail to bring the efforts of research to the help of our industries, we run the deadly risk of losing our means of livelihood. Willy-nilly, we must research, and with all our energy.

Here are various reasons for the encouragement of research: the benefit of the student, the addition to human knowledge, power, and riches, and the needs of defence, military and industrial. But I think we still have failed to include the most important reason of all, the real reason of which the others are only derivatives. It is that the spirit of research is like the movement of running water, and the absence of it like the stagnation of a pool. Scientific research, in its widest sense, implies, of course, far more than exploring the questions of physics and chemistry and biology. It is not a religion; but it is the act of one. It is the outcome of a belief that in all things which we try to do we may by careful seeking and by a better understanding do them better; that the world, far beyond what we can see of it on the surface, is full of things which it would be well for us to know. It is our duty and our gain to explore: we have always grown by doing so, and we believe that the health of our souls depends on doing so. Shall we sit still when there are difficult questions to solve, and when the answers may give us new insight and new power? There is a hesitation which would beg us not to push forward lest we come to think less of the world. As against this, research is an act of faith in the immensity of things. There is no end to the search: it is a poor thought that there might be.

The spirit of research would drive us all to work to the utmost of our power, believing that the more we do and the better we do it, the better for the work and lives of others. It is vigorous, hopeful, trustful, and friendly; it adds always new interest and new life. It is a spirit which should run through all our activities, and not be found in laboratories only. It is, in fact, a spirit which is essential to us as a nation trying to rise above ourselves to better things. All our efforts to encourage research have before them not only one or other such immediate object like that to which I have already referred, but also this great ideal.